TECHNOLOGIES USED FOR TRUCK CLASSIFICATION AND METHODOLOGIES FOR ESTIMATING TRUCK VMT

Professor Rahim F. Benekohal
Phone (217) 244 6288
Fax (217) 333 1942
rbenekoh@uiuc.edu

Montty Girianna
Phone (217) 333 5967

girianna@uiuc.edu

University of Illinois at Urbana-Champaign

Department of Civil and Environmental Engineering
University of Illinois at Urbana Champaign
Newmark Civil Engineering Laboratory
205 N. Mathews Ave.
Urbana, IL 61801

Submitted for publication in the proceeding of the 82nd
Transportation Research Board Annual Meeting
January 2003, Washington, DC.

7,485 words including tables and figures

TECHNOLOGIES USED FOR TRUCK CLASSIFICATION AND METHODOLOGIES FOR ESTIMATING TRUCK VMT

Rahim F. Benekohal and Montty Girianna
University of Illinois at Urbana-Champaign

Abstract

This paper presents the results of a national survey of all state department of transportation (DOTs), including Puerto Rico, on technologies used for trucks classification and methodologies used for estimating truck vehicle miles traveled (VMT). Over two-thirds of the state DOTs returned the survey. Different procedures by state DOTs were found to classify trucks, to adjust truck data from short-term counts, and to calculate truck VMT. To classify trucks, the majority of state DOTs followed the FHWA's 13 categories (F-13 scheme). The products from two manufacturers, Peek Traffic and Diamond Traffic Products with a variety of sensors, dominated the classification devices used by state DOTs. The most utilized sensor for short-term classification counts was pneumatic tube sensors. The duration and the number of truck classification counts (machine or manually) varied by state DOTs. With machine classifiers, state DOTs collected short-term (less and 24-hour as well as 48-hour counts) and continuous truck data for a variety of state's highway coverage. Truck data were collected using machine classifiers unless certain conditions, such as congested highways, would demand collecting the data manually. To adjust truck data from short-term classification counts, most state DOTs developed their adjustment factors from continuous volume counts (not truck counts) and used them for adjusting truck volumes. Some state DOTs used adjustment factors for truck that are different than those for cars. For all state DOTs, the general practice of truck VMT estimation was based on traffic counts. When truck data was available, state DOTs directly calculated truck VMT by multiplying truck ADT and the length of a roadway section, and when the data was not available, truck VMT was indirectly calculated as a fraction (percentage) of total VMT. For the state highway systems, state DOTs generally relied on the first (direct) method since the resources were normally available and the standards for conducting traffic counts were also available. However, some states were lacking the necessary resources to adequately sample ADTs on the local road systems. As a result, many state DOTs used the indirect method to calculate truck VMT.

INTRODUCTION

Truck data collection and reporting is an important program that state DOTs must maintain to comply with the Federal Highway Administration requirements. The objective is to obtain vehicle miles traveled by trucks using data from a sample of roadways. Truck data collected from samples is then converted into more meaningful measures such as annual average-daily truck traffic (AADTT) and truck VMT. State DOTs maintain different types of classification programs ranging from short-term (24-hour or less), 48-hour, to continuous counts, covering both the highway performance monitoring system (HPMS) and non-HPMS sample sections. To calculate truck VMT, some state DOTs collect truck data from a comprehensive classification program while others still rely on a volume count program. A variety of classification equipment is used with different sensor technologies. Different procedures are also used by state DOTs to calculate truck VMT from the short-term truck data.

The Illinois Department of Transportation (IDOT) is interested in evaluating the methodology for determining truck VMT and the technologies available for truck classification. IDOT is also interested in evaluating the current distribution and number of (classification) counting locations in light of the changes in travel patterns, increase in truck traffic, and recent advances in technology for measuring and counting traffic. A national survey was conducted to evaluate the state of practice on equipment and methodologies used to determine truck VMT. The accuracy of traffic count-based truck VMT estimates is determined by the quality of the truck data used for the estimation. Therefore, the sample size, sampling locations, and equipment used to collect truck data are very important factors in determining truck VMT.

This paper presents the results of a national survey on methodologies and technologies used to compute truck VMT. Detailed information of the survey results are described elsewhere (Benekohal and Girianna, 2002) The first two sections describe the results of survey on how truck data is collected, followed by the description of classifying sensors and devices for classification counts used by state DOTs. Next, procedures to adjust truck data collected from short-term classification are presented. The fourth section discusses current methodologies used by state DOTs to estimate truck VMT. The paper concludes with findings and recommendations for future works.

VEHICLE CLASSIFICATION TECHNOLOGIES

Vehicle classifiers

Recent developments in sensor technologies permit the use of a variety of concepts for classifying trucks on highways. The choice of technology depends on many factors such as cost, reliability, precision, life span, installation, maintenance, and type of data it provides. Vehicle classification technologies currently used can be grouped into three major categories: axle based, vehicle length based, and machine vision (visual) based. Axle-based Classifiers measure the number of axles and axle spacings and are used to group vehicles into the 13 categories recommended by the Federal Highway

Administration (FHWA). The axle spacings are determined from the speeds of vehicles and the times the axles passed over the sensors. Vehicle speed is obtained by measuring the time the front axle traveled from the first to the second sensors. The number of axles and axle spacings are used to determine the class of vehicles. The accuracy of these classifiers depends on several factors including the type of sensors used (loops, tubes, piezoelectric, etc), roadway geometry conditions at the site of classification, installation and maintenance, and classification algorithms. Errors in the form of unclassified vehicles are normally due to either the incorrect measurement of the number of axles, a considerable change of vehicle speed over the sensors, and types of vehicles that do not fit into any of the prescribed classes of vehicles.

Unlike axle-based classifiers, vehicle length-based classifiers use vehicle length to group vehicles into different classes. A single or combinations of different types of length sensors are normally used, including loops, piezoelectric, or electrical contact closures. These classifiers may classify vehicles into fewer categories than the FHWA 13 vehicle classes because of difficulties, for example, in differentiating a single long vehicle unit from two smaller/shorter units hitched together. Despite the limitations, these classifiers, particularly with loop detector systems, remain popular in some states partly because fewer categories are sufficient for a variety of traffic monitoring purposes, and partly because the loop system is low cost technology with high reliability. The third group of vehicle classifiers is machine vision-based classifiers. These classifiers, also known as image processing or artificial vision, are technologies that combine video imaging with computerized pattern recognition. The technologies are developed to provide a system that does not require installation of sensors on roadway pavement (non-intrusive sensors) and to collect more detailed information about vehicles such as width, height, and character profile of individual vehicles. Normally a video camera is used to record video images (frames) that are taken at contiguous time instants spaced at regular time intervals. A digitizer converts the frames into digital signals that are sent to a computer for extraction of vehicle features. These visual-based classifiers, however, are subject to the drawbacks of measuring speed accurately and the difficulties in differentiating among closely spaced vehicles. In addition, image-sensing technologies are also subject to inaccuracy caused by occlusion (the blocking of the line of sight by a second vehicle).

Sensor Technologies

To obtain accurate vehicle classification, research and development of new sensor technologies are underway. Inductive loops, pressure-sensitive treadles, and several non-intrusive sensor technologies, such as light-beam and light-curtain based sensors, are developed for use to classify vehicles. Inductive loops, wires placed in channels cut into the pavement, classify vehicles by sensing the metallic mass of vehicles. Pressure-sensitive treadles placed in frames and installed in the pavement are used to determine the number of axles, number of wheels, and direction of a vehicle crossing the treadles. Four types of treadles are available depending on the physical principle used to convert the pressure of a vehicle’s wheel into electrical signals recognized by the logic units of the treadles. The first is electromechanical treadles. These devices are in widespread use for low-speed applications. The second is resistive rubber treadles, which are similar to electromechanical treadles, but use resistive rubber rather than metal for contact closure.

They are specified to operate accurately at a wider range of speeds. The third is optical treadles. These devices utilize infrared beams inside a tube. When beam is broken due to the pressure of a vehicle's wheel, an electrical signal is generated. These devices are specified to be accurate at higher speeds and have a long life and low cost of maintenance. The fourth is piezoelectric treadles. These devices use special material inside a tube that generates an electric current when subjected to pressure caused by crossing vehicles. The devices are accurate classifying vehicles at low and high speeds.

In addition, several non-intrusive sensor technologies have been introduced to classify vehicles. At least two types of light emission based technologies are currently available: light beam and light curtain devices. Light beam devices consist of a single infrared light beam that is broken as a vehicle passes through the beam. They are used to detect vehicle presence and vehicle height. The functionality of light beam devices is limited in that they cannot accurately separate vehicles with trailer hitches or provide a profile of the vehicle. Another disadvantage of light beams is that the single beam of light is transmitted through vehicle windows without impediment, thereby causing the appearance of a separation of the vehicle where none exists. Light curtain devices emit multiple horizontal light beams to measure vehicle presence and profile. A transmitting tower sends light beams across the lane to a receiving tower. As a vehicle breaks the light beams, a two-dimensional profile of the vehicle can be produced. Trailer hitches can be detected down to approximately one-half inch. Other non-intrusive techniques are developed by scanning vehicles using ultrasonic waves, infrareds, or laser beams. Scanning devices generate radiation at various frequencies to detect vehicle presence and profile. Ultrasonic scanners emit ultrasonic waves, which are reflected back to the transmitting device to detect vehicle presence and two-dimensional profile. Ultrasonic scanner, however, are subject to distortion from air turbulence and changes in temperature and humidity. Infrared scanners are used to separate and profile vehicles using a vertical or horizontal infrared scanning camera system. The output is two-dimensional images, which are compared to vehicle classification templates to determine vehicle type. Laser scanners are capable of detecting and classifying vehicles operating in high speed, high volume conditions. Output from the device is processed to produce 3-dimensional images that are compared to stored templates of various vehicle profiles to determine vehicle type.

SURVEY METHOD

A survey of 50 state DOTs and Puerto Rico DOT on equipment and methodologies used for determining truck VMT was conducted. The surveys solicited information on how the DOTs collected truck data and used it to calculate truck VMT. Three groups of questions were included in the survey: coverage of classification counts, analyzing and processing truck data, and calculating truck VMT. The coverage includes questions with respect to the number of classification counts on different types of roadways, types of area (rural and urban), congested or non-congested sections, HPMS and non-HPMS sections, and whether truck data is collected for short or long-term duration. The purpose is to examine the state-of-practice of truck data collection. The second group of questions includes how truck data is analyzed and expanded from sample to represent the annual truck volume by types. Truck adjustment factors and whether they are differentiated according to vehicle or truck types, rural or urban, etc., used by state DOTs are the central issue in this group. The last group includes how truck data is used and what other sources of data or methods that DOTs used to calculate truck VMT.

The survey was sent to DOTs through mail services and followed by another if DOTs did not respond in four weeks. DOTs completed the survey and returned it in three different ways, i.e., mail services, fax, and as an attachment of an email. When further clarification is needed, DOTs is contacted by phone or emailed. A complete survey was then coded and stored in electronic files using Microsoft Access. SAS codes were developed to analyze the survey results.

SURVEY RESULTS

A great majority of DOTs (36 out of 51) returned the survey. This section briefly presents the survey results. The results are grouped into five categories, i.e., sample size and field data collection, types of truck classification counts, classification equipment, adjustment factors, and truck VMT calculation.

Sample size and field data collection

For almost all state DOTs returning the survey, the procedure to determine the sample size for classification counts follows the FHWA Traffic Monitoring Guide (TMG) and AASHTO's Guidelines. Some state DOTs use the guidelines with conjunction with other criteria that depend on the objective of data collection, such pavement management, truck traffic projection, etc. HPMS sample requirements also determines the number of classification counts in many state DOTs. A compromise between the resources available and the need to cover the entire state highway systems determines the final decision in the number of classification counts. Once the sample size is determined, truck classification data is collected annually either in-house or by contractor staff, or both (see Table 1). Thus, for example, for 18 state DOTs (50%), almost all of the truck classification data is collected by their staff. To classify trucks, a great majority of states use the number of axles and axle spacing as the only variables or in conjunction with other variables, such as vehicle length and/or vehicle weight. State DOTs neither use vehicle length alone as the classifying variable nor the combination of vehicle length and vehicle weight. Vehicle types follow the FHWA F-13 scheme. Some state DOTs regroup vehicles into a smaller number of vehicle types. Colorado DOT, for example, regroups the F-13 categories into three categories. Vehicle types 1, 2, and 3 of the F-13 categories are grouped as passenger vehicles, vehicle types 4, 5, 6, and 7 are grouped as single-unit trucks, and vehicle types 8 to 13 are grouped as combination trucks. Similarly, Illinois DOT uses three different categories where vehicles are grouped according to the length of vehicle. Passenger vehicles (PV) are 0-21 feet in length, single-units (SU) are between 22 and 40 feet, and vehicles longer than 40 feet are categorized as multi-units (MU).

Types of classification counts

Truck classification counts are categorized by the duration along which truck data is collected: short-term (24-hour or less) and continuous. In addition, whether or not the classification data are collected on HMPS sections is also presented in this section. Truck classification data is manually collected when traffic conditions do not allow collecting data using automatic classification devices.

The number of short-term (24-hour or less) classification count stations is presented in Table 2 (a). These stations include those on the HPMS sections. As shown in the table, two state DOTs (Illinois and Virginia) collect 24-hour or less truck classification data in a large number of stations. Illinois DOT collects truck data at 3,300 locations, and Virginia DOT collects the data at 2,100 locations. These sites are located on interstate, arterial, and collector roadways. No count sites are located on local roads. Some DOTs that do not have short-term (24-hour or less) classification count stations (indicated by zero in the last column of Table 2 (a)) have extensive 48-hour classification count stations. Arkansas, for example, has very extensive classification count stations on the HPMS sections for a longer duration. Louisiana DOT collects 48-hour data at 25 locations on interstate, 56 on arterial, and 27 on collector roadways. All short-term classifications at the North Carolina DOT are collected for 48 hours for machine counts, and 16 hours for manual sessions. The North Carolina DOT has 65 classification count stations on interstate, 350 on arterial, 200 on collector, and 30 on local roads. Wyoming collects classification data for 48 hours at 20 sites on interstate, 30 on arterial, 15 on collector, and five on local roads. Figure 1 (a) shows the number of short-term classification count stations per 1,000 miles of total highway systems for different state DOTs. The density of classification stations ranges from zero to 42 stations per 1,000 miles. Vermont DOT collects the short classifications at 612 locations on 14,274 miles of its highway systems, or 42 stations per 1,000 miles. Virginia DOT performs 2,100 24-hr classifications on 70,137 miles of its highway system, or 30 stations per 1,000 miles of highways. Illinois DOT used 3,300 short-term stations on 139,159 miles of highways, or about 24 stations per 1,000 miles. For these state DOTs, the density of short-term classification count stations is greater than 20. The density of short-term classification count stations in the remaining state DOTs is less than 20 stations per 1,000 miles.

In terms of the number of continuous or permanent classification stations, Oklahoma DOT has 290 permanent classification stations, which is more than any other state DOT. California DOT has 250 stations, and Virginia DOT has 247 stations. Table 2 (b) shows the number of permanent classification stations maintained by state DOTs and Figure 1 (b) shows the number of permanent classification stations per 1,000 miles of total highway systems. Idaho DOT has the highest permanent station density with 3.8 permanent stations per 1,000 miles of highway. Connecticut DOT has 3.6 permanent stations per 1,000 highway miles. Virginia ranks third with 3.5 stations per 1,000 highway miles. Eleven state DOTs operate at least one permanent station per 1,000 highway miles. The rest use less than one permanent station per 1,000 miles of highway.

Table 2 (c) shows the number of classification count stations on HPMS sample sections by state DOTs. Figures 2 (a) shows the density per 1,000 miles of highway for permanent. California and Oklahoma DOTs each maintain 250 permanent classification stations on their HPMS sections, which is more than any other state DOT. The densities per 1,000 miles of total highway is the highest for Idaho (2.8), followed by Oklahoma (2.3), Washington (1.9), Connecticut (1.8), California (1.5), and West Virginia (1.4). The remaining state DOTs maintain less than one station per 1,000 miles of highway systems.

The number of 48-hour classification count stations on HPMS sections also varies across state DOTs, as shown in Table 2 (c) and Figure 2 (b). Arkansas DOT operates 1,240 stations on HPMS sections, or about 12 stations per 1,000 miles of highway. Vermont and Washington DOTs each operate 600 stations. The density for Vermont is about 42 stations per 1,000 miles of highway, which is the highest density for 48-hour classification stations. Three state DOTs (New Jersey, Utah, and Washington) reported maintaining between five to ten stations on every 1,000 miles of highway. The rest of the responding state DOTs had less then five stations per 1,000 miles of highway. As seen in Table 2 (d), the duration of classification counts on non-HPMS sections varies across the states. The shortest classification count period was three to four hours at 28 locations in Idaho, and the longest count period lasted seven days at five locations in Nevada. The classification count cycles for non-HPMS sections also vary by state DOTs, ranging from a 12-month cycle (Arkansas and North Carolina) to a 72-month cycle (Kentucky).

To classify vehicles, seventeen state DOTs perform manual classification counts. The duration of the manual classification counts ranges from two to 48 hours. South Dakota DOT collects manual truck classification data for two to three hours. West Virginia DOT collects the data in different duration and times, such as three hours (7 to 10 a.m.), two hours (11 a.m. to 1 p.m.), and four hours (2 to 6 p.m.). Idaho DOT collects the data for four hours using software called “Genlog,” which was developed for a laptop computer. Arizona DOT collects truck data for six hours if AADT of roadway sections is less than 6,000. New Jersey DOT conducts manual classifications for eight hours (10 a.m. to 6 p.m.). North Carolina DOT collects the data for 16 hours from 6 a.m. to 2 p.m. (AM shift with 1/2 hour break), and from 2 p.m. to 10 p.m. (PM shift with 1/2 hour break). Four state DOTs (Iowa, Kansas, Michigan, and Wyoming) collect truck data for 24 hours. Michigan DOT collects the data for 12-16 hours. Wyoming DOT performs the 24 hour classification counts in three shifts of eight hours. One state DOT (Nebraska) collects the data manually for 32 hours, which is performed in four shifts of eight hours. Two state DOTs (Minnesota and Nevada) collect the manual data for 48 hours. Minnesota DOT also conducts 16-hour classifications along with the 48-hour classifications.

In order to collect truck data on congested roadway sections, some state DOTs use manual classification counts and some utilize automatic classifiers with more sensitive input sensors with different sensor configurations. The duration of manual classification varies among the DOTs ranging from 14 hours (Puerto Rico) to 24 hours (Kansas). Pennsylvania DOT uses the Weigh-in-Motion (WIM) devices and manual counts to collect data on congested sections. California DOT uses piezoelectric sensors, and South Carolina DOT uses piezoelectric sensors along with loop detectors. New Jersey DOT collects truck data per lane with two tubes and loops between the tubes. Nevada DOT uses an axle sensor, loop detector, and axle sensor configuration. Oklahoma DOT utilizes electronic switches in each lane, and Virginia DOT uses a portable system of loops and tubes.

Classification equipment

For short-term classification counts, a portable classification device with pneumatic road tubes are the most popular (32 state DOTs). Table 3 (a) lists portable vehicle classification devices used by state DOTs. The products from two manufacturers, Peek Traffic and Diamond Traffic Products, dominate the market. The products of Peek Traffic (Peek ADR 1000/2000 and Peek 241) and a variety of sensor technologies, for example, are used by 16 state DOTs. Permanent classification devices manufactured by Peek Traffic and Diamond Traffic Products, see Table 3 (b), are used by a considerable number of state DOTs. Fourteen state DOTs use the Peek ADR family, and 9 state DOTs use Diamond Traffic Products. Table 4 shows the degree of satisfaction on sensor technologies reported by state DOTs. The choices for the degree of satisfaction were “Very Unsatisfied”, “Somewhat Unsatisfied’’, “Somewhat Satisfied”, and “Very Satisfied”. The last column of the table shows the average score weighted by the number of state DOTs responding to the survey. The pneumatic road tubes were rated “Somewhat Unsatisfied” by seven DOTs, “Somewhat Satisfied” by 14 DOTs, and “Very Satisfied” by 11 DOTs. As a result, the average degree of satisfaction of this technology is (7x2+14x3+11x4) / (6+14+11)=3.13. Similarly, the average degree of satisfaction for each sensor technology was calculated. The degree of satisfaction for magnetic imaging and acoustic sensor technologies is the highest (4.0). However, only one state DOT uses the magnetic imaging technology and acoustic technology. The degree of satisfaction for the loop detector plus axle sensors is the next highest (3.41), followed by the WIM device (3.31), the pneumatic road tube (3.13), loop detector only (3.09), video image and electrical contact closure (3.0), microwave (2.50), and fiber optic (1.50) sensors.

Truck adjustment factors

A variety of procedures were reported to adjust truck data collected from short-term classification counts. Table 5 shows the types of traffic volume adjustment factors and their utilization by state DOTs. To expand truck data collected form less than 24-hour counts, some state DOTs uses the truck adjustment factors that are derived from truck counts, and thus the factors are different than those for passenger cars. As shown in the table, seven state DOTs use this procedure. Eleven state DOTs reported using the day-of-week adjustment factors to obtain monthly truck volume. Seasonal adjustment factors are used by 19 state DOTs to adjust the monthly data to yearly data. Eleven of these state DOTs apply the same adjustment factor for cars and trucks, while eight state DOTs implement different seasonal factors for cars and trucks. As shown in the table, only in five state DOTs truck data is expanded using all the adjustment factors (expansion, day-of-week and seasonal factors), and only three of these state DOTs (Minnesota, Nebraska and Pennsylvania) have implemented the three adjustment factors for trucks that different than that for cars. The truck adjustment factors are generally developed from truck data collected at continuous classification stations.

Truck VMT calculation

The majority of state DOTs (70%) returning the survey does not use sources other than traffic volume count data to calculate truck VMT. About 19% of the state DOTs (7 DOTs) use additional non-traffic data along with truck volume count data, such as the State Fuel Tax Report (Idaho, Virginia, and Wisconsin) and weight-mile tax and flat fee tax data (Oregon). There are two different methods that state DOTs currently used to calculate truck VMT. The first method calculates truck VMT on a highway segment basis and it is made by multiplying truck ADT by the length of a roadway section. This method requires truck data on the highway segment and it is usually represented as a percentage of the total ADT. Truck data is collected at classification count stations. Truck ADT on a highway segment between two consecutive classification count stations is calculated by averaging the estimated truck ADT at the stations, and then multiplying the average by the distance between the two stations. California DOT, for example, uses this method and truck VMT for the state highway system is calculated based on 3,800 truck counting locations on its state highway system. The second method calculates truck VMT by multiplying total VMT (by functional class) by the average truck percentages (by truck types). This method is basically the HPMS method developed by the FHWA for estimating truck VMT. This method requires state DOTs to calculate the total VMT and the statewide average truck percentage for a specific roadway group (by functional class and vehicle types). The total VMT is obtained from the HPMS database that records AADT for HPMS highway segments. The HPMS database is updated annually through the state DOTs' traffic monitoring program. The average truck percentages by roadway functional class and vehicle types are obtained from truck data collected at permanent classification sites. Two state DOTs (Arizona and Colorado) use the two methods simultaneously and implement the first method (by highway segment) for their State Highway System and the second method for all public roads or area-wide HPMS sections, not just the state highway system.

ANALYSIS OF SURVEY

Problems with sensor devices and the need to use non-intrusive systems

The current practice of vehicle classification requires a number of different sensors, including pneumatic tube sensors and loop detectors. The most utilized sensor for short-term classification is the pneumatic tube sensor. Two primary problems with this system are addressed. One is its high failure rate (unclassified vehicles) in some jurisdiction, and other is that it is not the most favorable sensor based on site-specific constraints such as congested traffic conditions or where longer-term classification is needed along a high-speed section of freeways. The main problems with the tube systems are related to installation, level of accuracy, and the durability of the tubes. The tube system is not reliable on Freeways or Interstates, where interference with traffic to install and maintain the tubes in the pavement has become unfeasible. The tubes are very vulnerable to human errors at the time of installation causing a high rate of unclassified vehicles. Moreover, the tubes cannot stay down on the pavement for a long time and tend to stretch, thus affecting the accuracy of classification. Using inductive loop detectors alone in congested traffic conditions frequently overestimates the number of trucks because passenger cars with light trailers are counted as single unit trucks. The detectors can appropriately classify large trucks, but misclassify small trucks. The installation of this sensor is considered to be labor intensive. In addition, this type of sensors has a telemetry problem along with high failure rates for installation. The piezoelectric treadles are relatively new technology and require extensive oversight during installation since many electrical contractors are still not familiar with a piezoelectric sensor. Moreover, this technology requires extensive maintenance once it is installed, and during operation, it is very sensitive to temperature. Any significant change in temperature results in calibration changes. Similar to a loop detector, this sensor technology also has telemetry problem along with high failure rates for installation.

State DOTs offered several solutions to alleviate the problems due to the inferiority of sensor devices on a congested section. One should use visual based classification at locations where the conventional sensors, such as road tubes and loop detectors, are impractical, or alternatively, one may perform a manual classification count to provide some measures of truck volume. The use of more sophisticated inductive loop systems such as IVS-2000 by U.S. Traffic Corporation or the Peek Idris® Smart Loops potentially reduces the rate of classification failures. Wisconsin DOT uses the Peek Idris® Smart Loops for its annual continuous classification programs.

The use of non-intrusive sensor technologies

Non-intrusive classifiers are increasing in prominence due to high volume on urban freeways, where interference with traffic to install and maintain classifying devices has become unfeasible. These newer classifiers potentially reduce traffic delay and eliminate safety issues normally associated with the installation and maintenance of the inductive loop or treadles-based classifiers. However, the lack of familiarity of these relatively new sensor technologies and relative simplicity of the inductive loop and tube systems are among the factors that encourage state DOTs to continue using the inductive loop and tube systems.

Fewer truck types

For truck VMT purposes, fewer truck categories than the FHWA scheme are more practical from state DOT's point of view and it provides better results in terms of quality of outcomes. The categories are, for example, light trucks, single-units, combination vehicles, and multi-trailer trucks. Three categories are sufficient for states with few multi-trailer trucks. Fewer categories are made because volumes in many of the FHWA 13-categories are generally very low. When volumes within a vehicle category are low, the adjustment factors computed for those vehicles become unstable and, thus, inaccurate. A highly aggregated category provides stability to the factors computed.

Truck adjustment factors different than vehicles

It is important to distinguish the adjustment factors for truck and for cars as truck volumes vary over time and space differently than car volumes (TMG 2000). However, only a few state DOTs implement adjustment factors for trucks different than for cars. The majority of state DOTs relies on the adjustment factors derived from total volume. For state DOTs that implement truck adjustment factors different than cars, two procedures are followed. The first is the "specific road" approach, and the second approach is "group truck factor" approach. In the first approach, truck data collected from continuous counts is used to develop "road specific" adjustment factors. Thus, any short-term classification count collected on a specific roadway is adjusted using factors from the nearest continuous classification counter on that roadway. The second approach requires roadway sections be grouped according to both roadway functional classification and truck travel patterns. The travel patterns are generally governed by the amount of long distance "through" trucks compared to the amount of local trucks, the existence of large truck generators, and the presence or absence of large populations that require the delivery of freight and goods. In this approach, deciding roadway groups are part of the procedure. Virginia DOT, for example, uses both approaches to obtain annual average daily truck traffic (AADTT), while California, Iowa and Pennsylvania DOTs use the group factor approach.

Virginia DOT uses the truck day-of-week and seasonal variation factors to obtain AADTT for 24-hour and 48-hour classification counts. These factors are road specific and developed based on continuous classification counts on all major roads in the state. A short classification count taken on a specific road is adjusted using factors taken from the nearest continuous classification counts on that road. On its national highway system, one continuous classification count is associated with adjacent short-term counts. On other systems, a group of continuous counts is used to develop factors. Iowa DOT uses adjustment factors developed for different groups of roadway sections that are clustered according to their functional classification, area type, and other criteria (park, municipality, etc). Eight groups are defined: rural interstate, municipal interstate, rural primary, municipal primary, secondary, state parks, municipal streets, and other routes. In addition, the factors are developed for two different types of trucks: single-unit and multi-unit trucks. For a specific type of truck and for a specific month when truck data are collected, there are seven different truck factors, each for a different day. Similar to Iowa, Pennsylvania DOT uses a group of continuous classification counts to develop adjustment factors and clusters its roadway sections into ten different traffic pattern groups (TPG) based on highway functional classification, geographic area, and urban/rural characteristics. Using the hourly percentage truck factors (expansion factors) developed for each TPG, truck data that is collected for less than 24 hours is first expanded to a 24-hour volume. The 24-hour data is then processed to annual daily truck traffic through the application of a "day of week by month" truck factor, combining day-of-week and seasonal variation truck factors. The expansion factors are developed using traffic data that is collected statewide from 1,400 automatic classification counts. The "day of week by month" factor is developed based on continuous truck data obtained from the Pennsylvania Turnpike Commission toll collection facilities.

The "road specific" procedure requires a large number of continuous classification counts but provides considerable insight into the pattern of truck movement within the state. The major advantage of having a specific adjustment factor for a specific roadway is that it reduces errors associated with applying average factors to compute AADTT. It also reduces the number of short-term classifications that are required because the continuous counts also provide classification data. Furthermore, it simplifies the calculation of the adjustment factors and their application. However, this approach is costly since one has to maintain a large number of continuous counters. A factor computed for a specific road is not applicable to any other road. When roadways are quite long and their truck patterns vary over their length, an adjustment factor taken on a section in the western half, for example, may not be applicable to a section on the same road in the eastern half. This situation is problematic since it not only requires a larger number of continuous counters, but also it creates a difficulty in deciding the location of the short-term classification counts relative to the two continuous counts. The accuracy of adjustment factors also becomes questionable as the distances between the short-term counts and the continuous counts become longer.

The major drawback of current procedure for calculating truck VMT

For all state DOTs, the general practice of truck VMT estimation is based on traffic counts. When truck data is available, state DOTs directly calculate truck VMT by multiplying truck ADT and the length of a roadway section, and when the data is not available, truck VMT is indirectly calculated as a fraction (percentage) of total VMT. For the state highway systems, state DOTs generally rely on the first (direct) method since the resources are available and the standards for conducting traffic counts are also available. However, some states are lacking the necessary resources to adequately sample ADTs on the local road systems. As a result, many state DOTs use the indirect method to calculate truck VMT. A current procedure to calculate truck VMT with indirect method has many fundamental drawbacks. The most noticeable one is that the truck percentage factor that applied to total VMT is obtained from a small sample size for truck classification, mostly on HPMS sections, and the percentage factor is calculated using a procedure that relies on the characteristic of total traffic, not the characteristic of truck traffic. As a result, the quality of outcomes is questionable. Illinois DOT, for example, calculate truck VMT based on a limited number of FHWA's 13-category classification counts (approximately 100 locations annually collected on HPMS sections) and on a comprehensive set of volume counts. The truck percentage factor is obtained from the classification counts. This procedure overestimates VMT for Multi Unit trucks by 23 % for Interstate Urban and by 6 % for Interstate Rural using 1996 truck data. Only on Minor Urban Arterials does this procedure underestimates truck VMT, i.e., by 10 percent. Overall deviation is about 11.5 % higher than the true value for Multi Unit trucks. To obtain more accurate truck VMT, state DOTs must first expand the coverage of classification counts to include the highway state system and local roads. The procedure of sample sizing that is based on the truck flow patterns need to be explored. With a proper sample sizing, the truck percentage factors can be calculated with a higher degree of accuracy.

CONCLUSIONS AND RECOMMENDATIONS

This paper presented the results of a national survey of state DOTs on the technologies used for classifying trucks and the methodologies used for estimating truck vehicle miles traveled (VMT). To compute truck VMT trucks, the majority of state DOTs relies on truck count programs that is annually performed. With the FHWA's 13 categories, truck data was collected using either machine or manual classifiers. Truck data was collected using machine classifiers unless certain conditions, such as congested highways, would demand collecting the data manually. The products from two manufacturers, Peek Traffic and Diamond Traffic Products with a variety of sensors, dominated the classification devices used by state DOTs. For short-term classifications, most state DOTs used portable devices with pneumatic road tubes, and some used the combination of the tubes with other sensors, such as loop detectors and piezoelectric and fiber optic sensors. For continuous classifications, the majority of DOTs used permanent devices equipped with loop detectors and piezoelectric sensors. To adjust truck data from short-term classification counts, most state DOTs developed their adjustment factors from continuous volume counts (not truck counts) and used them for adjusting truck volumes. Some state DOTs used adjustment factors for truck that are different than those for cars. Truck adjustment factors were further distinguished based on truck types and area types. Two different methods for truck VMT calculation were used by state DOTs. When truck data were available, state DOTs used the direct method, i.e., multiply truck ADT and the length of a roadway section. When the data were not available, truck VMT is indirectly calculated as a fraction (percentage) of total VMT. For the state highway systems, state DOTs generally relied on the direct method since the resources were normally available and the standards for conducting traffic counts were also available. However, some states were lacking the necessary resources to adequately sample ADTs on the local road systems. As a result, many state DOTs used the indirect method to calculate truck VMT.

The density of classification counts per 1,000 miles of total highway system considerably varied by state DOTs. The annual traffic management and data collection program of state DOTs still focused on a comprehensive volume counts. Truck adjustment factors that are needed for expanding truck data collected from short-term counts are inevitably based on the characteristic of total volume (not truck volume). It is necessary to encourage state DOTs to include classification counts in their annual traffic monitoring program, and it is also necessary to develop a procedure for determining an optimal sample size for truck data collection, a procedure of how truck data is expanded, and a methodology of how truck VMT is calculated.

REFERENCES

1. Benekohal R.F., and Girianna, M. (2002), *Evaluation of Methodology for Determining Truck Vehicle Miles Traveled in Illinois*, A report submitted to Illinois Department of Transportation.

2. Federal Highway Administration. (2000), *Traffic Monitoring Guide*, Draft 5th edition.

LIST OF TABLES

1. TABLE 1 Field truck data collection
2. TABLE 2 (a) Number of short-term (24-hr or less) classification count stations
3. TABLE 2 (b) Number of permanent classification count stations
4. TABLE 2 (c) Number of classification count stations on HPMS sections by state
5. TABLE 2 (d) Number of classification count stations on non-HPMS sections by state
6. TABLE 3 (a) Portable classification devices used by state DOTs
7. TABLE 3 (b) Permanent classification devices used by state DOTs
8. TABLE 4 Satisfaction level of state DOTs on various input sensors and equipment technology
9. TABLE 5 Adjustment factors and their utilization by state DOTs

LIST OF FIGURES

1. FIGURE 1 (a) Density of short-term (24-hour or less) classification count stations by state
2. FIGURE 1 (b) Density of permanent classification count stations by state
3. FIGURE 2 (a) Density of permanent classification count stations on HPMS sections by state
4. FIGURE 2 (b) Density of 48-hour classification count stations on HPMS sections by state

Truck Data Collection	No. of State	(%) *
Almost all of truck classification data is collected by DOT staff	18	50
Mostly by DOT, but some by contractor staff	6	16
Almost all of truck classification data is collected by contractor staff	0	0
Mostly by contractor, but some with DOT staff	4	11
Other	6	17
No Response	2	6

* Based on those responding

TABLE 1 Field truck data collection

No.	State	Interstate	Arterial	Collector	Local	Total
1	AK	25	20	20	-	65
2	AR	0	0	0	0	0
3	AZ	12	25	9	0	46
4	CA	-	-	-	-	-
5	CO	0	150	75	0	225
6	CT	0	0	0	0	0
7	HI	-	-	-	-	-
8	IA	0	2	250	150	402
9	ID	30	95	14	0	139
10	IL	400	2,600	300	0	3,300
11	IN	-	-	-	-	-
12	KS	21	151	61	31	264 *
13	KY	60	170	70	10	310
14	LA	0	0	0	0	0
15	MA	0	0	0	0	0
16	MI	-	-	-	-	-
17	MN	15	30	-	-	45
18	MT	20	150	30	0	200
19	NC	0	0	0	0	0
20	NE	40	301	153	84	578
21	NH	10	10	10	0	30
22	NJ	40	162	50	82	334
23	NV	0	0	0	0	0
24	OK	40	80	50	0	170
25	OR	-	50	50	-	100
26	PA	35	100	100	25	260
27	PR	13	40	24	2	79
28	SC	58	161	63	0	282
29	SD	17	40	12	4	73
30	UT	40	300	150	70	560
31	VA	-	-	-	0	2,100
32	VT	12	600	-	-	612
33	WA	9	10	0	0	19
34	WI	5	120	30	5	160
35	WV	-	-	-	-	-
36	WY	0	0	0	0	0

- There is no information (no response)
* Data is collected for both 24 (or less) and 48 hours.

TABLE 2 (a) Number of short-term (24-hr or less) classification count stations

No.	State	Interstate	Arterial	Collector	Local	Total
1	AK	-	-	-	-	-
2	AR	17	20	4	1	42
3	AZ	9	13	5	0	27
4	CA	250 *	-	-	-	250
5	CO	19	36	18	0	73
6	CT	37	38	0	0	75
7	HI	-	-	-	-	-
8	IA	20	51	10	0	81
9	ID	39	115	15	0	169
10	IL	10	26	1	0	37
11	IN	-	-	-	-	-
12	KS	0	0	0	0	0
13	KY	10	13	2	.	25
14	LA	0	0	0	0	0
15	MA	0	0	0	0	0
16	MI	22	24	-	-	46
17	MN	3	2	-	-	5
18	MT	18	40	9	1	68
19	NC	12	17	9	2	40
20	NE	11	19	3	0	33
21	NH	2	0	0	0	2
22	NJ	20	54	1	0	75
23	NV	6	0	0	0	6
24	OK	70	150	70	0	290
25	OR	0	0	0	0	0
26	PA	6	3	0	0	9
27	PR	9	2	-	-	11
28	SC	11	4	3	-	18
29	SD	14	27	11	11	63
30	UT	40	39	3	0	82
31	VA	87	100	60	0	247
32	VT	4	5	-	-	9
33	WA	150	0	0	0	150
34	WI	16	38	2	-	56
35	WV	15	23	12	0	50
36	WY	11	15	5	1	32

- There is no information (no response)
* Including those stations on arterials and collectors

TABLE 2 (b) Number of permanent classification count stations

No.	State	Permanent	48-hour
1	AK	10	60
2	AR	30	1,240
3	AZ	27	46
4	CA	250	50
5	CO	25	50
6	CT	37	15
7	HI	-	-
8	IA	57	15
9	ID	123	90
10	IL	3	100
11	IN	-	-
12	KS	0	100
13	KY	46	100
14	LA	0	109
15	MA	0	0
16	MI	8	40
17	MN	0	-
18	MT	60	180
19	NC	20	280
20	NE	35	35
21	NH	2	-
22	NJ	25	331
23	NV	6	63
24	OK	250	150
25	OR	0	250
26	PA	9	0
27	PR	11	35
28	SC	18	300
29	SD	63	-
30	UT	20	300
31	VA	-	-
32	VT	9	600
33	WA	150	600
34	WI	54	40
35	WV	50	100
36	WY	13	12

- There is no information (no response)

TABLE 2 (c) Number of classification count stations on HPMS sections by state

No.	State	12-hour	24-hour	48-hour	other
1	AK	-	-	-	0
2	AR	-	-	240	-
3	AZ	-	-	0	0
4	CA	-	-	-	0
5	CO	-	-	175	-
6	CT	0	0	30	-
7	HI	-	-	-	-
8	IA	0	10	0	0
9	ID	-	-	40	28 (4)+
10	IL	100	3,200	-	-
11	IN	-	-	-	-
12	KS	-	-	200	-
13	KY	-	-	100	-
14	LA	0	0	0	-
15	MA	-	-	-	-
16	MI	-	-	250	-
17	MN	-	-	150	50 (16)
18	MT	-	-	20	-
19	NC	-	-	250	100 (16)
20	NE	-	-	-	115 (32)
21	NH	30	0	0	0
22	NJ	-	-	94	-
23	NV	0	0	5	5 (7 days)
24	OK	-	10	10	-
25	OR	-	-	-	-
26	PA	0	0	0	25 (8)
27	PR	20	-	15	-
28	SC	-	-	10	-
29	SD	-	60	-	-
30	UT	-	-	-	-
31	VA	-	-	-	-
32	VT	-	-	-	-
33	WA	-	-	-	-
34	WI	0	0	-	0
35	WV	-	-	-	-
36	WY	-	-	-	-

- There is no information (no response)

+ Numbers in parentheses indicate the duration of classification counts in hours

TABLE 2 (d) Number of classification count stations on non-HPMS sections by state

No.	State DOTs	Classifiying Devices
1	AK	Peek ADR 2000 (Tubes)
2	AR	ITC Traffic A.C.E (Tubes), TC III (Tubes)
3	AZ	Golden River Archers (Tubes)
4	CA	Peek (Tubes), Diamond (Tubes)
5	CO	ITC (Tubes), Diamond (Tubes), Diamond (Loops, Piezoelectrics)
6	CT	(Loops, Piezoelectric, Tubes) *
7	HI	**
8	IA	Peek ADR 1000 (Tubes), TraffiCam 3 (Tubes)
9	ID	Diamond (Tubes), Diamond (Loops)
10	IL	Nu Metric Hi-Star NC-97 (Magnetic Imaging), Peek 241 (Tubes)
11	IN	**
12	KS	Diamond Unicorn (Tubes)
13	KY	Peek ADR (Tubes), ADR 1000 (Piezoelectrics), ADR 2000 (Loops)
14	LA	ADR 1000, Peek 241 *
15	MA	Peek 241 (Tubes)
16	MI	Peek (Tubes), Diamond/Phoenix (Tubes); ITC (Fiber Optic)
17	MN	TimeovK (Tubes), Timeovk (Loops)
18	MT	Diamond (Tubes), ECM (BL Piezoelectrics)
19	NC	Peek ADR 1000 (Tubes)
20	NE	Diamond (Tubes)
21	NH	GK 5000 (Tubes)
22	NJ	(Tubes) *
23	NV	Diamond (Tubes), PAT Equipment (Capacitance Mat/Loops)
24	OK	Peek ADR 1000 (Tubes), Mitron (Tubes, PET), Peek-Swtich (PET)
25	OR	Peek (Tubes), Diamond (Tubes)
26	PA	(Tube)*
27	PR	ADR 2000 (Loops), ADR 2000 (Piezoelectrics)
28	SC	Peek 241 (Loops, Piezoelectrics), Peek 241 (Tubes)
29	SD	Diamond (Tubes)
30	UT	ADR (Tubes); ADR (Loops)
31	VA	Peek 241 (Tubes), Peek ADR (Loops), ITC *
32	VT	Jamar Trax II (Tubes)
33	WA	GK 5000, 6000 (Tubes), Diamond/Unicorn (Tubes)
34	WI	Peek 241/ADR (Tubes), Peek 241/ADR (Tubes/Loops)
35	WV	(Tubes) *
36	WY	WIM (Capacitive mat), Diamond 2001 (Tubes), Diamond Phoneix (Tubes), Diamond 2001/ Phoeni

* No Information available on either classification devices or sensor types
** No response

TABLE 3 (a) Portable classification devices used by state DOTs

No	State DOTs	Classifying Devices
1	AK	Peek ADR 2000 (Loop-Piezoelectric-Loop)
2	AR	Peek ADR (Piezoelectric-Loop-Piezoelectric), Peek TC III (Loop-Piezoelectric-Loop), ITC RakTel (Piezoelectric-Loop-Piezoelectric)
3	AZ	IRD ICC 530 (Loops), IRD WIM *
4	CA	Peek (Piezoelectrics-Loops), Diamond (Piezoelectrics-Loops), PAT (Bending Plate-Loops), IRD (Bending Plate-Loops)
5	CO	Diamond (2 Loops), Diamnod (2 Loops and Piezoelectric), ECM WIM (1 Loop and 2 Piezoelectrics), IRD WIM (1 Loop and 2 Piezoelctrics)
6	CT	Vibracoax Encapsulated Sensors (Piezoelectric), Vibracoax Uneancapsulated Sensors (Piezoelectric)
7	HI	**
8	IA	Peek ADR 2000 (Loops and/or Piezoelectric), TraffiCam 3 (Loops and/or Piezoelectric)
9	ID	Diamond (2 Loops), Hestia WIM (2 Piezoelectric and Loop)
10	IL	Peek ADR (Loop-Piezoelectrics), Peek 241 (Loop-Piezoelectric), RakTel (Loop-Piezoelectric)
11	IN	**
12	KS	**
13	KY	Peek ADR 1000 (Loops), Peek ADR 2000 (Piezoelectrics)
14	LA	**
15	MA	IRD WIM (Piezoelectric), ECM WIM
16	MI	Diamond (Piezoelectrics), PAT (Piezeoelectrics and Bending Plates)
17	MN	IRD WIM (Wim Scales)
18	MT	Diamond (Piezoelectric), ECM (Piezoelectric)
19	NC	Peek ADR 3000 WIM (Loops and Piezoelectrics)
20	NE	Diamond Unicorn (Loops and Piezoelectrics), Diamond Phoenix (Loops and Piezoelectrics)
21	NH	WIM (Piezoelectrics) , WIM (Load Cells) *
22	NJ	IRD TCK 540 (Piezoelectric), IRD TCK 500 (Dynox), IRD WIM (Piezoelectric)
23	NV	Diamond (Piezoelectrics-Loops), PAT (Bending Pate-Loop-Piezoelectrics), PAT (Piezoelectrics-Loops), ECM (Piezoelectric-Loops)
24	OK	Peek ADR (Piezoelectrics or Loops), Peek 241 (Piezoelectrics or Loops), IRD 1060 (Piezoelectrics or Loop)
25	OR	**
26	PA	(Loop/Piezoelectrics) *
27	PR	ADR 3000 (Loops or Piezoelectrics)
28	SC	Peek 2000 (Loops and Piezoelectric)
29	SD	PAT (Bending Plate)
30	UT	Peek ADR (Loops), Peek ADR (Piezoelectrics)
31	VA	Peek ADR (Piezoelectrics), IRD WIM (Piezeoelctrics or Loops)
32	VT	IRD (Piezoelectrics or Loops)
33	WA	IRD WIM (Bending Plates-Piezoelectrics), Diamond Phoenix (Piezoelectrics), Golden River (Loops), EIS/RTMS (Radar)
34	WI	Peek ADR/241 (Loop-Piezoelectrics), Peek ADR 4000 (Loop IDRIS), PAT DAW 200 (Loops-Bending Plate)
35	WV	PAT WIM (Bending Plate-Loop), PAT (Piezoelectrics-Loops), Peek (Piezoelectrics-Loops), ECM (Piezoelectrics-Loops)
36	WY	WIM (Piezo Electric) *, Diamond Phoenix (Loop-Piezoelectric-Loop)

* No information available on either the classifycing devices or the sensor types
** No response

TABLE 3 (b) Permanent classification devices used by state DOTs

No	Sensor/Equipment Technology	No. of DOTs	Very Unsatisfied (score=1)	Somewhat Unsatisfied (score=2)	Somewhat Satisfied (score=3)	Very Satisfied (score=4)	Average Score
1	Road Tube	32	-	7	14	11	3.13
2	Magnetic Imaging	1	-	-	-	1	4.00
3	Electrical Contact Closure	4	-	2	-	2	3.00
4	Loop Detector Only	11	1	-	7	3	3.09
5	Loop Detector plus Axle Sensors	22	-	1	11	10	3.41
6	Video Image	1	-	-	1	-	3.00
7	Photoelectric Sensor	0	-	-	-	-	-
8	Fiber Optic	2	1	1	-	-	1.50
9	Laser/Lider	0	-	-	-	-	-
10	Acoustic	1	-	-	-	1	4.00
11	Microwave	2	-	1	1	-	2.50
12	Infrared	0	-	-	-	-	-
13	Ultrasonic	0	-	-	-	-	-
14	Radio Wave	0	-	-	-	-	-
15	WIM Device	29	1	3	11	14	3.31

TABLE 4 Satisfaction level of state DOTs on various input sensors and equipment technology

Type of Adjustment Factor	Cars versus Trucks	No. of DOTs	State DOTs
Short Term Expansion Factors	The same factor for trucks and cars	1	WV
	Different factor for trucks and cars	7	CA IA IL MN NE OR PA
Day-of-week Adjustment Factors		11	AZ CA MN NE PA PR UT VA VT WV WY
Seasonal Adjustment Factors	The same factor for trucks and cars	11	AR AZ CA ID MT NJ PR VA VT WA WV
	Different factor for trucks and cars	8	IA IL MI MN NE PA UT WY

TABLE 5 Adjustment factors and their utilization by state DOTs

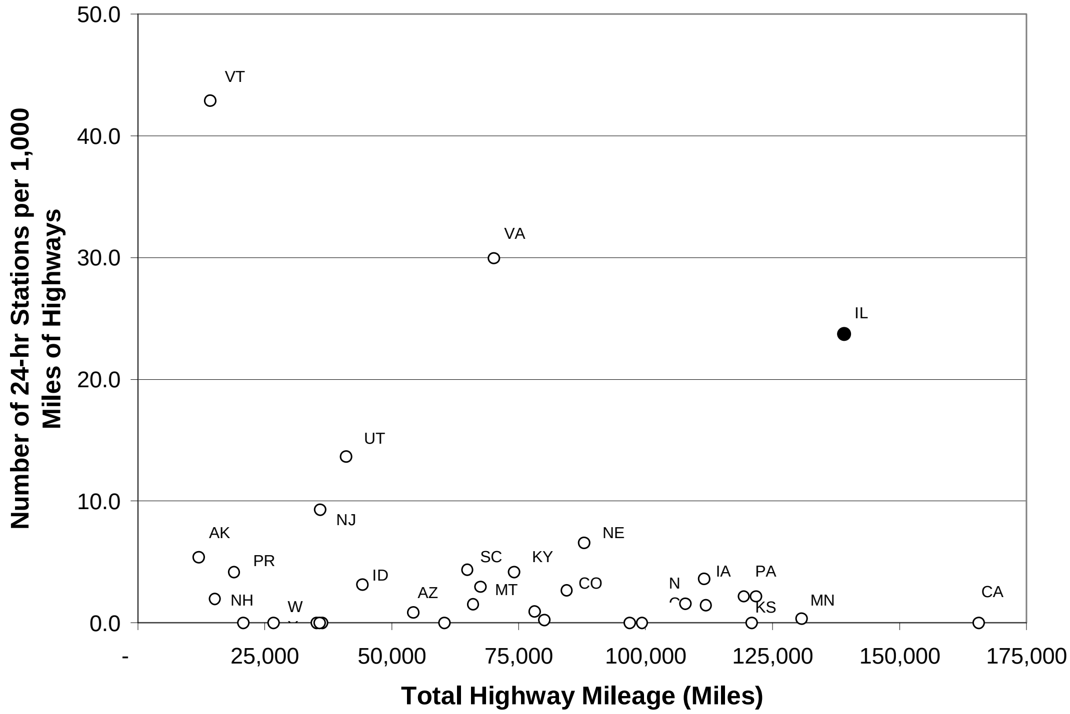

FIGURE 1 (a) Density of short-term (24-hour or less) classification count stations by state

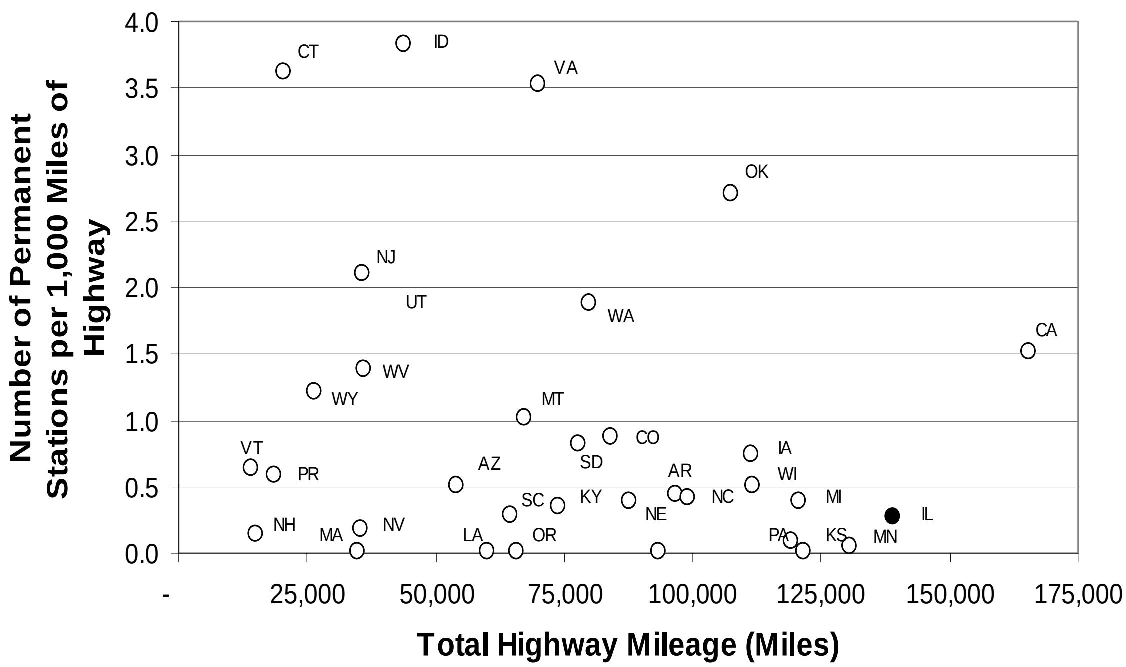

FIGURE 1 (b) Density of permanent classification count stations by state

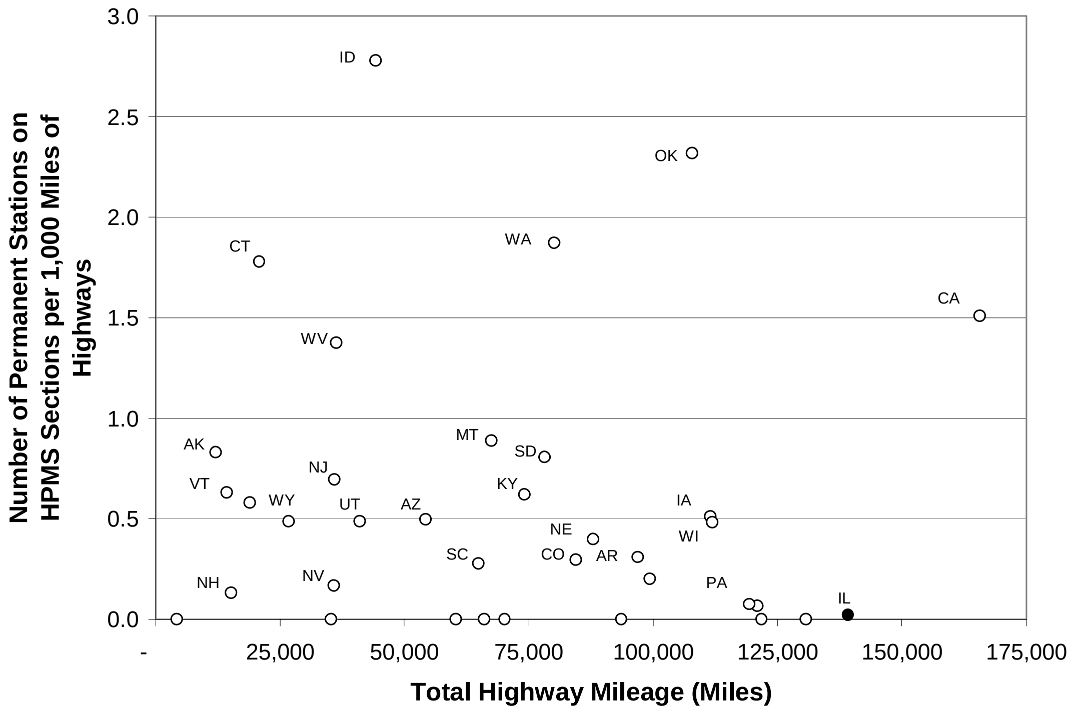

FIGURE 2 (a) Density of permanent classification count stations on HPMS sections by state

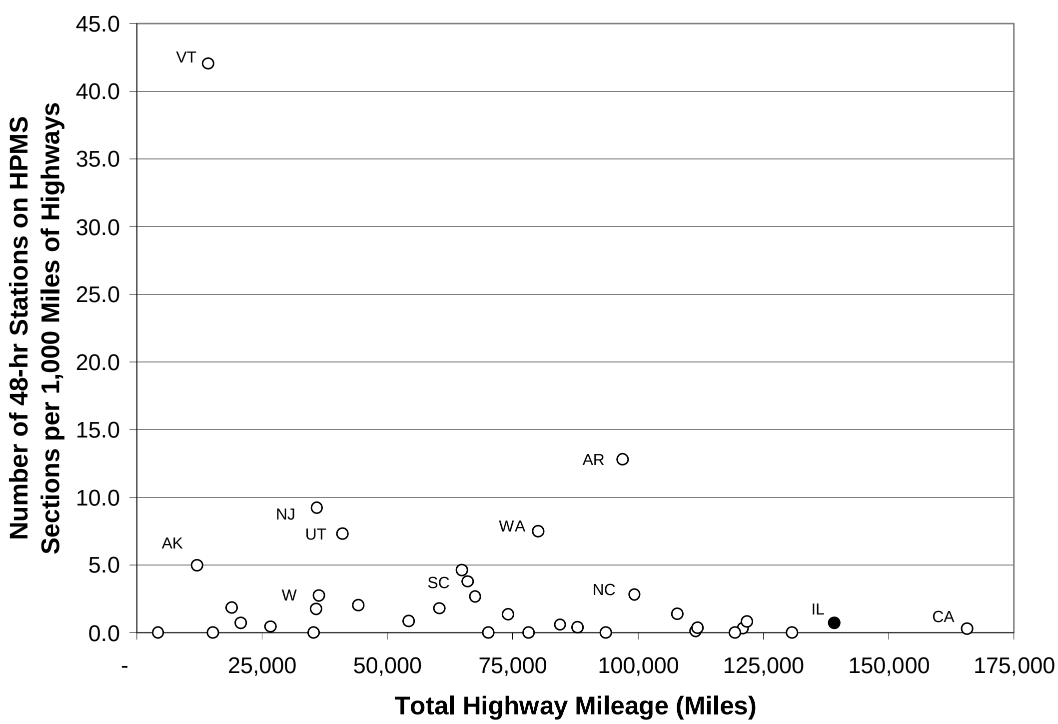

FIGURE 2 (b) Density of 48-hour classification count stations on HPMS sections by state